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MARKET POTENTIAL FOR

Fats and Oils as Plasticizers

UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Marketing Service
Marketing Economics Research Division
Market Development Research Division

PREFACE

This study is part of a broad program of research conducted by the United States Department of Agriculture to assist in the development of markets for agricultural products. The information on the market potential for fats and oils in plasticizers is designed to help management in appraising the importance of the outlet, and in making plans for expanding the use of fats and oils in plasticizers.

Acknowledgment is made to personnel of the Eastern, Northern, and Southern Utilization Research and Development Divisions, Agricultural Research Service, who provided technical assistance in planning the work and reviewing the report. Dr. Daniel Swern, of the Eastern Division, and Dr. Leo Goldblatt, of the Western Division, made many valuable suggestions during the course of this study.

The Tariff Commission made up a special tabulation of equivalent fatty acid use in plasticizer production for the years 1954 to 1957.

This study was made under the general supervision of Marshall E. Miller, Market Development Research Division. Frederick J. Poats was the project supervisor.

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DEFINITION OF TERMS

Plastics, polymers, or large molecules are composed of many building blocks which were small molecules of matter called monomers.

Copyolymers are formed by polymerizing two or more different monomers into large homogeneous molecules.

Polymerization is a chemical reaction by which molecules are linked together to make large molecules.

Thermoplastics are polymers which can be melted and reshaped without destroying their polymeric properties. These materials fuse before decomposition can occur and they are soluble, within limits, in solvents without decomposition.

Plasticized plastics are polymers made flexible over a wide temperature range by physically mixing them with a plasticizer.

Polyethylenes are thermoplastics with inherent flexibility. They do not require addition of plasticizer to give them flexibility.

Vinyl polymers contain a primary repeated carbon-hydrogen grouping.

Acetylene is a gaseous hydrocarbon of great chemical reactivity and is used as the basic building block for vinyl thermoplastic compounds.

Polyvinyl chloride (PVC) plastic is polymerized vinyl chloride.

Plasticizers are high boiling point organic fluids which are compatible with thermoplastics throughout a wide temperature range.

Aliphatic (acyclic) plasticizers are straight linked carbon chain compounds.

Cyclic plasticizers contain a ring of carbon atoms in their molecular structure. Cyclic compounds that are aromatic contain a benzenoid structure.

Esters or salts are compounds formed from an alcohol and an acid. The process is called esterfication.

Adipates are organic esters of adipic acid and various alcohols.

Butyl stearate is an ester of butyl alcohol and stearic acid.

Diisodecycl phthalate is a diester product of 2 molecules of isodecyl alcohol and 1 molecule of phthalic anhydride.

Phthalic anhydride is the commercial product form of phthalic acid.

Di-2-ethylhexyl phthalate (DOP) is the diester of 2 molecules of 2 ethylhexyl alcohol and 1 molecule of phthalic acid.

Epoxidized fats and oils are chemically modified fats which have been partially oxidized. The epoxies contain the 3-membered oxirane nucleus, carbon-carbon-oxygen.

Fatty acids are organic acids first isolated from fats which contain a terminal or alpha position carboxyl group (COOH).

Polybasic fatty acids are fatty acids containing two or more carboxyl groups.

Saturated fatty acids do not contain any multiple bonds between carbon atoms.

Unsaturated fatty acids contain one or more multiple bonds between carbon atoms.

MARKET POTENTIAL FOR FATS AND OILS AS PLASTICIZERS

By Richard Hall, agricultural economist,
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SUMMARY

Plasticizers are used to add flexibility to certain plastics. They constitute a growing industrial market for animal and vegetable fats and oils. Production of fat-based plasticizers in 1963 is expected to exceed 100 million pounds as compared with 72 million pounds in 1957, and about 40 million pounds in 1954.

To produce the 72 million pounds of plasticizers in 1957, about 55 million pounds of fatty acids were used. About 61 million pounds of fats and oils were required to produce this amount of acids.

Total plasticizer production in 1958 was 418 million pounds. Fat-based plasticizers were an estimated 16 percent of the total, phthalic-acid plasticizers 57 percent of the total. However, since 1954, the rate of growth in production of fat-based plasticizers has been greater than the growth in total plasticizer production.

Desirable product characteristics contributed by phthalate plasticizers to plastics are greater than those supplied by fat derivatives. Price trends have also favored the use of phthalates. Phthalic acid plasticizers were higher in price than many fatty acid plasticizers in 1949, but were lower in price in 1959. Furthermore, price fluctuations for phthalates have been less than for fats and oils. For these reasons the phthalate plasticizers have been the general purpose plasticizers used in volume in flexible plastics. Nevertheless fat-based plasticizers with unusual properties are being used in growing quantities.

The simple fat-based plasticizers in most years are relatively cheap but they are somewhat at a disadvantage with respect to properties they impart to the final plastic. They have limited use in lowering overall costs as secondary plasticizers in combination with other plasticizers. More complex types of fat-based compounds exhibit particularly outstanding characteristics but their high cost limits their use to specialty products or to use in combination with other plasticizers. New epoxidized fat-based plasticizers, however, will retard deterioration of a plastic. This attribute has led to their growing use.

The epoxidized plasticizers were developed by the Eastern Utilization Research and Development Division and were put into commercial use in 1954. By 1957 an estimated 29 million pounds were produced, or nearly 40 percent of all fat-based plasticizers. Thus the key to growth in use of fat-based plasticizers has been improved properties. The properties contributed by epoxy plasticizers have offset the higher price per pound paid for the epoxies in comparison with phthalate plasticizers.

Several factors influence the potential market for fats and oils in plasticizers. One is the expected growth in total production of plasticizers. Trends in plasticizer production indicate that production will exceed 600 million pounds by 1963. A moderating factor is that after 1963, there may be growth in production of plastics which do not require a plasticizer. To date plasticized plastics and non-plasticized plastics largely have had

different markets. Both have grown, taking advantage of the opportunities from a rapidly expanding industry. However, greater substitutability is a definite possibility, although the extent can not be accurately assessed at this time. Other factors include the success of research designed to produce plasticizers suitable for all purposes from cheap raw materials. With the exception of simple esters of oleic, palmitic, and stearic acids, fat derivatives suitable for use as plasticizers cost more per pound than most plasticizers based on other source materials. Economic displacement of fat plasticizers may be considerable if quality can be matched. However, continued technological research directed toward the development of new fat-based plasticizers with superior properties can maintain or expand this market for fatty acids.

BACKGROUND AND METHODOLOGY

Small amounts of farm-produced fats and oils are used in the production of plastics. As plastic products are being produced in increasing numbers, they can provide a growing market for fats and oils.

A spectacular growth occurred from 1939 to 1958 in the number and volume of synthetic organic materials that can be used in a wide variety of plastic products. Total production of plastic materials, as recorded by the Tariff Commission, increased from 200 million pounds in 1939 to 4,500 million pounds in 1958. However, production of thermoplastics requiring a plasticizer did not increase in volume at the same rate as the total production of plastics.

The principal users of plasticizers have been polymers and copolymers of vinyl chloride (PVC). PVC was not commercially important until the mixture of plasticizer and PVC was introduced. Additional plasticizer using plastics are the cellulosics and special rubber compounds. Plasticizers produced in volume are those most compatible with the technical and economic requirements for making plasticized PVC products.

Cyclical (aromatic) compounds have been the principal plasticizers used in PVC. Acyclic (aliphatic) plasticizers, principally based on fatty acids, have also been important. Cyclic and acyclic materials, of different chemical structure, make plastics of similar but differentiated characteristics.

The cyclic plasticizers are principally derived from byproducts of coke production, petroleum processing, and natural gas. Fatty acids are largely derived from fats and oils from plants and animals.

The principal cyclic acid used in plasticizers is phthalic acid. A great number of fatty acids are used for plasticizers: Azelaic, oleic, pelargonic, and stearic acids from animal fats; lauric acid from coconut oil; palmitic acid from cottonseed oil or palm oil; and ricinoleic and sebacic acids from castor oil.

Research by the Eastern Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture, has led to the commercial introduction of new plasticizer materials; epoxidized fatty esters and oils and vinyl stearate. The Southern Utilization Research and Development Division introduced acetoglycerides for use in films and coatings.

The overall objective of this study was to appraise the market potential for animal and vegetable fats and oils in plasticizers. Greater use of fats in plasticizers would partially offset the loss of their market for other industrial products, such as soap. Additional industrial outlets for fats and oils are greatly needed. Specific objectives were:

(1) To determine the competitive economic position of fat-derived plasticizers in relation to plasticizers produced from other materials.

(2) To determine what physical and chemical characteristics plasticizers of fatty acid origin should have if their use is to be expanded.

(3) To appraise the present market and future outlook for all kinds of plasticizers.

(4) To review present technological research programs to determine need for further research.

Personal interviews were obtained with members of 86 firms representing suppliers of raw materials, manufacturers of plasticizers, and manufacturers of plastics.

About 60 percent of the interviews were with users of plasticizers and 33 percent with manufacturers of plasticizers.

Results of the personal interviews were analyzed along with information obtained from a review of economic and scientific literature, and from answers to a questionnaire.

PLASTICIZER PRODUCTION TRENDS 1949-1958

All Plasticizers

The growth in plasticizer production since 1949 has generally followed the dynamic growth of the plastics industry in general, and of certain thermoplastics in particular. Many new thermoplastics have been developed since 1949, and the number of firms manufacturing them has increased. Plasticizer production in 1958 at 418 million pounds exceeded the 1949 total of 158 million pounds by 165 percent (table 1).

TABLE 1.--Plasticizer production, 1949-58

Year	Cyclic plasticizers		Acyclic plasticizers		Grand total
	Phthalic anhydride plasticizers	All other cyclic plasticizers	Sum of oleic, sebacic and stearic acid esters[1]	All other acyclic plasticizers	
	Million pounds	*Million pounds*	*Million pounds*	*Million pounds*	*Million pounds*
1949.....	94	28	[2] 13	23	[2] 158
1950.....	143	38	[2] 15	36	[2] 232
1951.....	157	47	[2] 20	46	[2] 270
1952.....	150	44	[2] 19	44	[2] 257
1953.....	165	59	[2] 18	51	[2] 293
1954.....	171	57	23	50	301
1955.....	213	83	31	69	396
1956.....	237	78	33	69	417
1957.....	251	78	33	80	442
1958.....	237	75	23	83	418

[1] Fat-based esters separately identified in Tariff Commission reports for the entire period.

[2] Adjusted for esters classified as plasticizers 1949-53, reclassified as surface active agents, 1953.

U. S. Tariff Commission "Synthetic Organic Chemicals."

Tariff Commission data reveal that:

(1) An important amount of the growth in the plasticizer industry is accounted for by plasticizers that have become commercially important since 1949. (A commercially important plasticizer is arbitrarily selected as one the production of which exceeds 1 million pounds annually.) For example, the plasticizer produced in largest volume, di-2-ethyl hexyl phthalate, accounted for one-third of the production in 1949, but for only one-fifth in 1958, though production of DOP has continued to increase. Diisodecyl phthalate was not commercially important in 1949, but it made up one-twentieth of total commercial production in 1957 and 1958.

(2) Three times as many firms produced DOP in 1957 as in 1949, but they produced only about 1 1/2 times as much (table 2).

(3) The average production per firm of phthalate, and of other plasticizers not fat-based, was larger than that of firms using fatty materials. This factor can have significance in future competition, since straight chain carbon materials can be made from petrochemicals to duplicate fat structures.

Although manufacturers list over 300 separate compounds as plasticizers, less than 25 of these compounds comprise the bulk, according to Tariff Commission reports.

TABLE 2.--Number of manufacturers and production of selected plasticizers, 1949 and 1957

Plasticizers	1949			1957		
	Number of manufacturers	Production	Production percentage of all	Number of manufacturers	Production	Production percentage of all
Non fat-based:		*Million pounds*			*Million pounds*	
Di-2-ethyl hexyl phthalate.....	*Number* 6	51	*Percent* 32	*Number* 18	74	*Percent* 17
Tricresyl phosphate.....	4	[1] 11	7	6	[1] 30	7
Diisodecyl phthalate.....	--	--	--	14	24	5
Didecyl adipate....	--	--	--	10	1	([2])
Fat-based:						
Butyl stearate.....	9	1	1	9	6	1
Dibutyl sebacate...	4	2	1	7	4	1
Butyl oleate.....	6	1	1	7	2	1
Total.....	--	66	[3] 42	--	141	32

[1] Contains material used as motor fuel additive.
[2] Less than 0.5 percent.
[3] Adjusted to conform with rounded totals.

U. S. Tariff Commission "Synthetic Organic Chemicals."

Fat-Based Plasticizers

The continuous, separately reported fat-based plasticizers in Tariff Commission reports have been limited to oleates, sebacates, and stearates for the period 1949 to 1958 (table 1). Their indicated production from 1949 to 1957 was a remarkably stable percentage of total plasticizer production (table 3). However, these statistics do not include all fat-based plasticizers, as many fat derivatives are included in the "all other" acyclic column. Thus, a problem is created in using the statistics as published concerning fat-based plasticizers.

TABLE 3.--Selected groups of plasticizers as percentage of total plasticizer production

Year	Cyclic plasticizers			Acyclic plasticizers		
	Phthalic anhydride plasticizer	All other cyclic	Total cyclic[1]	Fat-based separately reported	All other cyclic[2]	Total acyclic[1]
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1949	59	18	77	8	15	23
1950	62	16	78	6	16	22
1951	58	18	76	7	17	24
1952	58	18	76	7	17	24
1953	56	20	77	6	17	23
1954	57	19	75	8	17	25
1955	54	21	75	8	17	25
1956	57	19	76	8	17	24
1957	57	18	75	7	18	25
1958	57	18	75	5	20	25

[1] Adjusted, after rounding.
[2] Includes some fat-based plasticizers, about 20 million pounds or 5 percent of total plasticizers, in 1957.

U. S. Tariff Commission. Computed from "Synthetic Organic Chemicals."

The materials under "all other acyclic" have increased in production at 2 1/2 times the rate of the separately reported fat-based materials. Compounds included in this column can not be separately reported because either the figures would reveal operations of individual firms, or because the source material for the plasticizer could not be identified. Our estimates indicate that fat-based plasticizers made up 16 percent of the total production in 1957 but less than 8 percent was identified in published data. The Tariff Commission made a special tabulation of "all other" columns containing fat-based plasticizers to avoid revealing the production of individual firms. This increased the coverage of fatty acids used which could be reported. However, not all fat-based plasticizer production was included in the totals. Our estimate of this volume has been added to Tariff Commission totals for 1957.

The most important fat-based plasticizers in terms of volume are the epoxidized fats and oils. A considerable portion of the growth in fat-based plasticizer production from 1954 to 1957 was due to the introduction of the epoxies. Estimated production of epoxidized fats and oils in 1957 was 29 million pounds. This is 40 percent of the total of plasticizers made from fatty acids.

The general groups of plasticizers show contrasting growth trends for individual plasticizers. Markets for some types of fatty acids have expanded, while markets for other acids have declined; but the total market has expanded. In table 4, the fatty acid

TABLE 4.--Fat-based plasticizers: U. S. production in terms of acid equivalents, 1954-1957

Fatty acid used	1954	1955	1956	1957
	Thousand pounds	*Thousand pounds*	*Thousand pounds*	*Thousand pounds*
Oleic acid	9,256	10,393	8,095	8,930
Stearic acid	5,540	8,236	8,989	8,185
Sebacic acid	3,554	5,225	6,259	6,851
Ricinoleic acid	4,244	3,592	4,295	3,808
Lauric acid	668	1,643	2,755	3,549
Palmitic acid	1,659	2,454	2,647	2,308
Glycol ester of capryl-capric acids	1,233	1,340	950	1,528
Other	172	67	167	500
Grand total	26,326	32,950	34,157	35,668
Adipic acid	3,253	3,963	3,282	3,487

Derived from a special tabulation by the U. S. Tariff Commission. Calculated use of acid in plasticizer production which was reported to the Tariff Commission. The total does not include acid used in esters which were not identified as to chemical formula.

equivalent of fat-based plasticizers identifiable in data collected by the Tariff Commission has been calculated for the 1954-57 period on the basis of a 95 percent yield of esters (plasticizers) from raw materials.[1]

In 1957 the total fatty acid equivalent used in the production of identified fat-based plasticizers in Tariff Commission reports was 35.7 million pounds (table 4). The increase in the total production from 1954 to 1957 was 9.4 million pounds or 35 percent. Three acids were used to a greater extent in 1957 than 1954: sebacic, lauric, and stearic. The largest volume fatty acid plasticizers, those based on oleic acid, were slightly lower in production in 1957 than in 1954.

From 1955 to 1957, increased production of separately reported fat-based plasticizers was mainly due to increases in lauric and sebacic acid ester production. The significance of this trend is that lauric and sebacic acid plasticizers are used for special characteristics in plasticizer thermoplastic systems.

Two types of fatty plasticizers not completely covered in table 4, are azelaic acid esters and epoxy materials. The problem is one of classification, as derivatives of azelaic acid and sebacic acid are also used in synthetic lubricants. The epoxy plasticizers may be identified only as polymerics without naming source materials.

The acid equivalent data indicate a rapid change from 1954 to 1957 in total fat-based plasticizer production. In addition to this growth is the increased production of epoxidized materials and azelaic acid derivatives.

Typical formulations of polyvinyl chloride contained about 50 percent polymers and 50 percent plasticizer. The proportion of epoxy plasticizer varied from 1 to 75 percent; however, in large volume uses the proportion was under 5 percent. Production of vinyl chloride plastics in 1957 was estimated at 29 million pounds or about 4-1/4 percent of the reported production of vinyl chloride polymers and copolymers.

Of the estimated 29 million pounds of epoxies produced, only an estimated 15 million pounds are included in the 1957 Tariff Commission totals. The remaining 14 million

[1] Plasticizers which could not be identified as to chemical structure were not included in this tabulation of acid equivalents.

pounds represents an addition to Tariff Commission figures. An additional 11 million pounds of fatty acid-based plasticizers is included in "all other" columns of Tariff Commission reports and not included in categories 1 and 2.

To the 6 million pounds of azelaic acid reported by the Tariff Commission, 6 million more pounds were added, as reported production was about half of apparent consumption.[2]

Estimated production of fat-based esters for plasticizers 1954 and 1957[1]

Categories	1954	1957
	Million pounds	
1. Separately reported esters of azelaic, oleic, sebacic, stearic, lauric, palmitic, ricinoleic acids and triethylene glycol di (caprylate-caprate)[2]	23	41
2. Estimated production of epoxidized fatty acid esters and oils not included in Tariff Commission's statistics for plasticizers	2	14
3. Estimated volume of fat-based esters not separately reported in Tariff Commission reports	11	11
4. Estimated production of azelaic acid esters for plasticizer use, not included in Tariff Commission totals	2	6
Total	38	72

[1] Estimates were made from statistics published by U. S. Tariff Commission, figures published by industry, and calculations arrived at in this study.
[2] "Synthetic Organic Chemicals," 1954 and 1957, U. S. Tariff Commission.

Fat-based esters include some fatty acid and alcohol. Plasticizers weigh more than the acid used in their production.

The average fat-based plasticizer contained 77 percent fatty acid. If we assume that a commercial process obtains 95 percent product from esterification, 55 million pounds of fatty acids were used in producing the 72 million pounds of fat-based plasticizers in 1957. To obtain the 55 million pounds of fatty acids, about 61 million pounds of fats and oils were used.

New more complex compounds were used as plasticizers for polyvinyl chloride, cellulosics, and chlorinated rubber compounds in 1958 and 1959. In particular, use of epoxidized fats and oils increased.

FACTORS AFFECTING CHOICE OF PLASTICIZER

Desired Plasticizer Properties

Research is now directed toward two opposing goals: To produce the ideal plasticizer for particular plastics, or to eliminate the need for plasticizers. The ideal plasticizer would have the following attributes:

(1) Permanence--The plasticizer must not be volatile to the point where processing loss is a physical hazard or economic problem. Mixed with a plastic it must be resistant

[2] Some materials used as high-temperature lubricants are included in this estimate of plasticizer use.

to extraction by soapy water, oil, and solvents. The plasticizer must not separate from the plastic under stress. It must not support fungus growth, be affected by ultra violet light, or be degraded by heat encountered in normal use. It must not cause the plastic to become brittle in normally cold temperatures.

(2) Compatibility--The plasticizer must maintain homogeneous mixture under conditions of processing and use, throughout the life of the product. The plasticizer must remain in suspension in solid or liquid materials in a mixture having a large proportion of plasticizer to plastic. A product with good compatibility characteristics is easy to process, and there is a minimum of processing loss.

(3) Special characteristics. An important characteristic is flexibility at low temperature. On the other extreme, the material must resist rapid deterioration when exposed to heat.[3] In proper formulation, the plasticizer must have good electric and dielectric properties. The plasticizer must not impair tensile strength or affect dimensional stability adversely. Plasticizers are used to improve the "feel" of a plastic by creating a soft, hard, or greaseless finish while remaining free of undesired odor. The plasticizer would be flame retardant. The physical characteristics of the material must be such that storing, shipping, and handling it will not require more complicated or costly procedures than for competing plasticizers.

The economic requirements for marketing large volumes of plasticizer are:

(1) The ideal plasticizer and plastic mixture must represent the low cost product in comparison with other materials made for the same purpose.

(2) Potential manufacturers of plastic products must be reasonably sure adequate supplies of plasticizer will be available, without too much fluctuation in price.

No ideal plasticizer is available and compromises have to be made. The phthalate plasticizers have no single physical characteristic that makes them outstanding. At the same time, they have no particularly undesirable characteristics. With regard to price, the simple fat-based esters of oleic and stearic acid usually cost less than the phthalates, but they do not have the physical attributes to compete with the phthalates. Azelates or sebacates with more limited, but superior individual plasticizer characteristics, are usually higher in price than the phthalates. The phthalate plasticizers are the large volume general purpose plasticizers. In most applications, plasticizers with a particular outstanding physical characteristic are used in combination with phthalates to make a product with desired physical characteristics.

Properties of Fat-based Plasticizers

Plasticizers produced from fats and oils differ more in the measure of a particular characteristic than in broad areas of use.

Fatty plasticizers, themselves, vary in their chemical structure. Four general types of fat-based plasticizers were in use in the 1954-58 period. The four general types were epoxidized fats and oils, esters of poly-basic fatty acids, polyesters, and the simple esters of fatty acids.

The most important type of fat-based plasticizers is the epoxidized fats and oils. Fatty plasticizers are modified by the physical characteristics of the source materials.

Epoxidized soybean oil produces a permanent plasticizer with stabilizing characteristics, especially in polyvinyl chloride formulations. The epoxy esters give improved low temperature flexibility to polyvinyl chloride formulations, and improved aging characteristics. The epoxies used solely as plasticizers are more expensive than the phthalates.

[3] At present all plasticizers which exhibit good low temperature flexibility are poor in the presence of heat; plasticizers resistant to heat deterioration show poor flexibility at low temperature.

To stabilize a phthalate plasticized plastic requires a more expensive stabilizer than the epoxy. Therefore, as plasticizer-stabilizers, the epoxies are relatively economical in comparison with a stabilizer and phthalate combination.[4]

Of almost equal importance in the consumption of fat in plasticizers are the azelates and sebacates. The azelate and sebacate plasticizers are particularly outstanding in improving the low temperature flexibility characteristics of polyvinyl chloride plastics. The azelates and sebacates are relatively expensive plasticizers. They are used either for special applications or to supplement other plasticizers. Esterfication of the dibasic acids, azelaic and sebacic, produces plasticizers with an outstanding characteristic of providing low temperature flexibility in polyvinyl chloride formulations.

A third type of fat-based plasticizer is the polyester. The polyesters form relatively permanent plasticizers which are particularly low in volatility and oil extraction. The polyesters are more expensive than the phthalates. The polyester materials are used for special products and are usually used in combination with other plasticizers.

The simple esters of fatty acids make up the fourth type of fat-based plasticizers. These plasticizers are poor in regard to odor, migration, oil extraction, and compatibility. The simple esters of fatty acids are low in price and are therefore used to reduce the overall cost of a plasticizer-plastic product in applications that do not require odorless, migration resistant, or oil resistant plasticizers.

Plasticizer Prices 1949-1959

A comparison of the prices of phthalic anhydride and oleic acid from 1952 to 1959 is used to illustrate the competitive pricing problem faced by fat-based materials in relation to phthalic derivatives. A comparison of prices of the two materials shows a distinct disadvantage for the derivative of fats and oils on two counts:

(1) Price instability and a rising trend in price for the fatty acid; and

(2) Stability and a declining price trend for phthalic chemicals.

The highest and lowest prices quoted each year from 1952 to 1959 are shown in table 5. Fluctuation in prices of oleic acid varied from 1/2 to 3-1/4 cents per pound and was 3 to 20 percent of the lowest price during the year. The average of yearly price fluctuation, 1.86 cents, for the years 1952 to 1958, was over three times that for phthalic anhydride.

The general trend in prices of the two materials also was different. The oleic acid price increased during the period while phthalic anhydride declined in price.

A comparison of prices of plasticizers of phthalic anhydride and oleic acid indicates still another factor. In figure 1, the downward trend in price for phthalic anhydride in table 5 is almost duplicated by the price of the plasticizer dioctyl phthalate. Oleic acid plasticizers have shown considerably more stability in price than oleic acid, but the average price of oleic acid plasticizers in recent years has been higher than the price of DOP. It is significant that dioctyl phthalate was 40 percent higher than the average price of oleic acid plasticizers in 1949, but 10 years later the phthalate was 20 percent lower in price. In general, derivatives of fats and oils for use as plasticizers are relatively

[4] Certain metallic salts in combination with epoxy plasticizer produce better stabilization than either alone.

TABLE 5.--High and low prices of oleic acid and phthalic anhydride, and range, 1952-1959

Year	Oleic acid Double distilled (white) tanks				Phthalic anhydride Tanks, freight equaled			
	High	Low	Range in price		High	Low	Range in price	
	Cents/lb	*Cents/lb*	*Cents/lb*	*Percent of low price*	*Cents/lb*	*Cents/lb*	*Cents/lb*	*Percent of low price*
1952.....	14.75	14.25	0.50	3.5	22.00	21.50	0.50	2.3
1953.....	14.50	12.75	1.75	13.7	21.50	19.50	2.00	10.3
1954.....	17.50	14.50	3.00	20.7	19.50	19.50	0.00	0.0
1955.....	19.00	18.00	1.00	5.6	19.50	19.50	0.00	0.0
1956.....	16.50	16.00	0.50	3.1	20.50	19.50	1.00	5.1
1957.....	18.75	15.75	3.00	19.0	20.50	20.50	0.00	0.0
1958.....	18.75	15.50	3.25	21.0	20.50	20.50	0.00	0.0
1959.....	[1] 16.00	[2] 16.00	0.00	0.0	[1] 20.50	[2] 16.50	4.00	24.2

[1] Oil, Paint, and Drug Reporter, January 19, 1959.
[2] Oil, Paint, and Drug Reporter, April 20, 1959.

HI-LO Chemical Price Issue, Oil, Paint, and Drug Reporter, 1952-58.

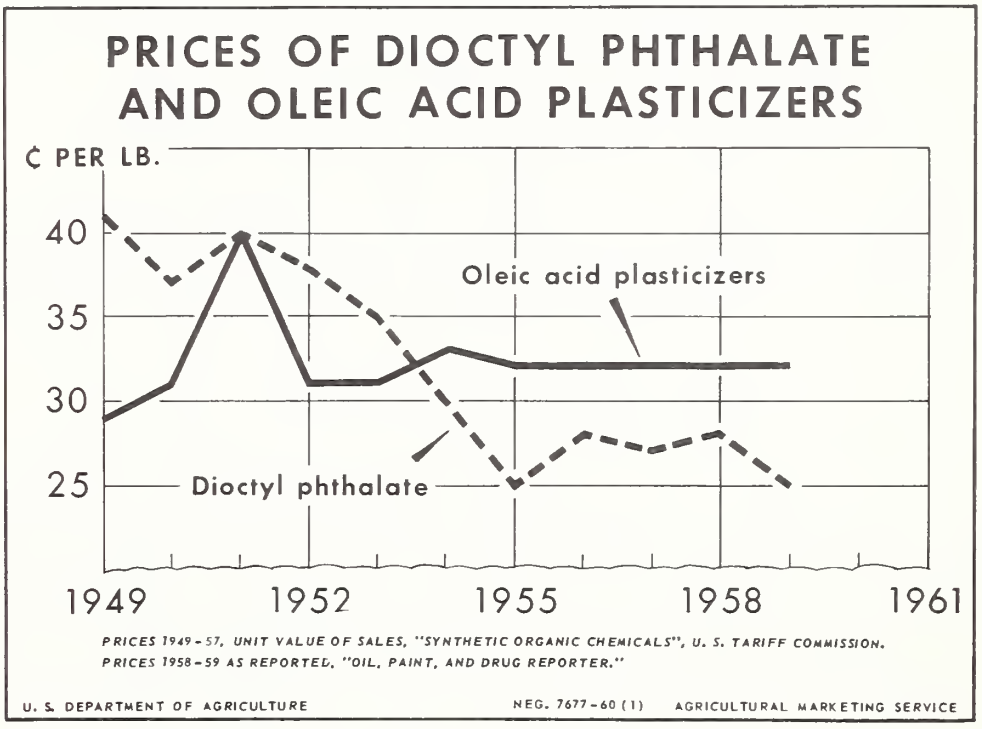

Figure 1

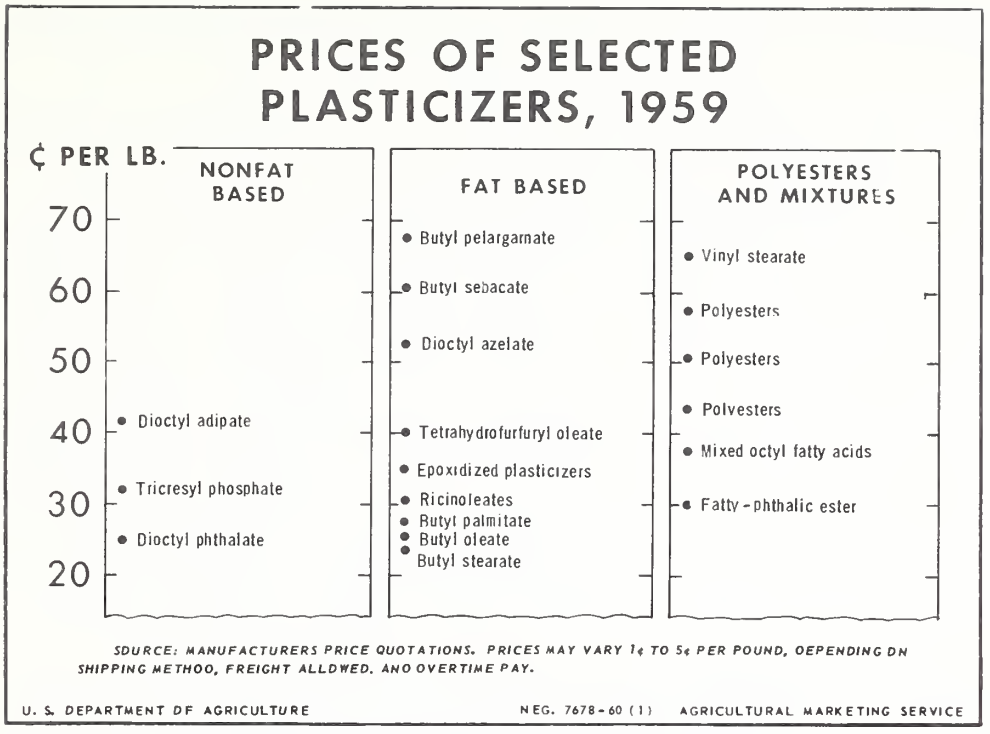

Figure 2.

high in price in comparison with dioctyl phthalate (fig. 2). Only the butyl alcohol esters of palmitic, oleic, and stearic acid are priced close to dioctyl phthalate, and these esters have drawbacks in application as plasticizers in comparison with dioctyl phthalate.

Figure 2 illustrates the economic reason that plasticizers from fat-based materials are generally limited to specialty uses.

Most other plasticizers cost more per pound than DOP. Prices generally have limited most fat-based materials to specialty applications.

Price Trends 1960-1963

A relatively greater production of high quality oleic acid is in prospect. This will tend to stabilize the price of oleic acid.

The downward trend in the price of phthalic anhydride is not likely to continue beyond the price existing early in 1959. Present production of phthalic anhydride seems adequate. It does not seem likely that new production methods or new investment in production will be called for.

Prices of fat-based plasticizers are not likely to be favorable enough to increase their use in the 1960-1963 period. The price of fats and oils will be determined by markets other than the plasticizer market. The expected reduction in price fluctuation of fat materials in the period 1960-1963 is based on technological advances which have made possible the substitution of one fatty material for another, to a greater degree than was possible before.

PRODUCTION OF MAJOR PLASTICS

Trends 1949-1958

Production of all thermoplastics in 1958 was 3-1/2 times that in 1949 (table 6). But production of the two major plasticizer-using plastics, polyvinyl chloride and cellulosics, did not expand as fast as that of other polymers (figure 3).

TABLE 6.--Production and index of production of thermoplastics 1949-1958

Year	Polyvinyl chloride		Cellulosics		Other thermoplastics		Total thermoplastics	
	Million pounds	*Index 1949=100*	*Million pounds*	*Index 1949=100*	*Million pounds*	*Index 1949=100*	*Million pounds*	*Index 1949=100*
1949.....	227	100	91	100	517	100	835	100
1950.....	325	143	130	143	735	142	1,190	143
1951.....	411	181	117	129	849	164	1,377	165
1952.....	356	157	98	108	888	172	1,342	161
1953.....	435	192	129	142	1,078	209	1,642	197
1954.....	397	175	123	135	1,197	232	1,717	206
1955.....	527	232	145	159	1,669	323	2,311	277
1956.....	637	281	147	161	1,820	352	2,604	312
1957.....	690	304	148	163	2,067	400	2,905	348
1958.....	657	289	141	155	2,083	403	2,881	345

Compiled from "Synthetic Organic Chemicals," U. S. Tariff Commission, annual.

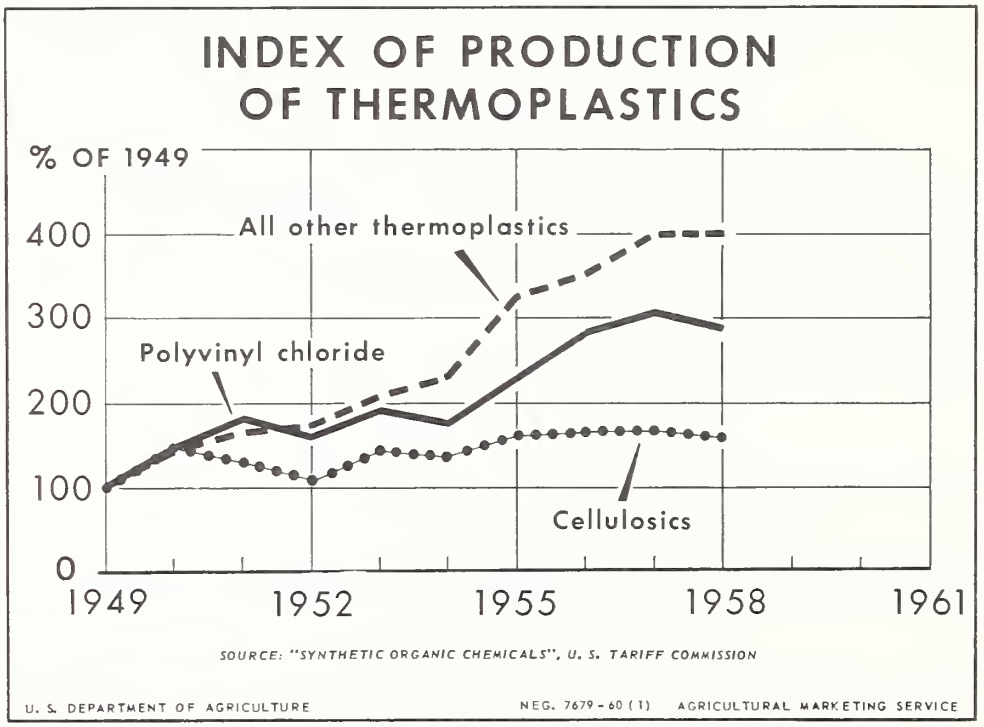

Figure 3

There was no sharp rise in the use of plasticizers in such plastic materials as polystyrene, nitrile, and chlorinated rubbers, flexible epoxy coatings, or special polyamides (nylons). Plasticizer production relative to production of PVC appeared to decline from 1954 to 1958 more sharply than it actually did because production of epoxidized fatty plasticizers and azelaic acid plasticizers was underreported. Lack of growth in production of cellulosics was significant enough to affect the overall growth in plasticizer use, and thus

TABLE 7.--Production of polyvinyl chloride and plasticizers, 1949-1958

Year	Polyvinyl chloride[1]	Plasticizers	Plasticizer as percent of vinyls
	Million pounds	*Million pounds*	*Percent*
1949	227	158	70
1950	325	232	71
1951	411	270	66
1952	356	257	72
1953	435	293	67
1954	397	301	76
1955	527	396	75
1956	637	417	65
1957	690	442	64
1958	657	418	64

[1] Polyvinyl chloride used to represent polyvinyl, chloride polymers and copolymers production as reported by the U. S. Tariff Commission.

Compiled from "Synthetic Organic Chemicals," U. S. Tariff Commission, annual.

production (table 7). Calculation of plasticizer production to PVC ratio may be adjusted for these factors to emphasize the strong relationship between PVC production and plasticizer production.

Another important threat to plasticizer production is the rapid growth in the production of polyethylenes.

Production of Polyvinyl Chloride (PVC) and Polyethylenes

A major virtue of PVC plastics is the versatility in physical characteristics of products that can be attained through control of polymer-plasticizer ratios used. The polyethylenes cannot be controlled in characteristics by the fabricator but can be used to produce flexible plastic films and sheets, and flexible extruded or molded products without the use of a plasticizer. It is in large volume outlets, such as package films, that polyethylenes have made the greatest market gains. As polyethylene production has increased since 1952, some applications have been competitive with vinyls. In the years 1949-58 there was no apparent substantial substitution of polyethylenes for PVC, despite rapid growth in production of the polyethylenes.

Polyethylene production which was equal to 33 percent of PVC in 1952 was 125 percent of PVC in 1958 (table 8). Continued increase in production and improvement in characteristics of polyethylenes, however, are likely to result in competition between polyethylenes and PVC in the future.

Vinyl Stearate and Competitive Materials

Plasticizers previously discussed do not become chemically bound to the polymer structure with which they are mixed, and are called external plasticizers. Vinyl stearate forms chemical bonds with polymers and is, therefore, called an internal plasticizer.

The copolymerization of vinyl stearate with another monomer, such as vinyl acetate, forms a plastic which is chemically or internally plasticized. Copolymerized materials cannot be altered in characteristics by the fabricator of products. The product fabricator can alter polyvinyl chloride plastic by mixing external plasticizers with the plastic.

TABLE 8.--Production of polyvinyl chloride and polyethylenes 1949-1958, estimated 1959-1963

Year	Polyvinyl chloride		Polyethylenes
	Million pounds		*Million pounds*
1949	227		[1] --
1950	325		[1] --
1951	411		[1] --
1952	356		[2] 105
1953	435		[2] 165
1954	397		[2] 260
1955	527		402
1956	637		557
1957	690		708
1958	657		865
	Trend[3]	Trend[4]	Trend[4]
1959	751	780	1,030
1960	802	850	1,200
1961	853	910	1,360
1962	904	960	1,500
1963	955	1,000	1,640

[1] Under 100 million pounds.
[2] Estimated from industry reports.
[3] Least squares--straight line projection.
[4] Graphic projection adjusted by market research study analysis.

Compiled from "Synthetic Organic Chemicals." U. S. Tariff Commission, 1949-1958.

Vinyl stearate can be made from acetylene and highly purified stearic acid. Commercial production began in the fall of 1958. The announced capacity of production is 2 million pounds per year.

The introductory price for the monomer is 65 cents per pound. This price is above many other materials proposed for use as internal plasticizers, but volume markets have not been established. The material has been used for coatings on paper and in flexible films. These uses could provide a volume outlet which would make possible the production of vinyl stearate at a lower price.

Trends 1959-1963

Announced plans of expansion in capacity for the production of polyethylenes and vinyl chloride materials indicate industrial capacities in excess of 1.5 billion pounds for polyethylenes and 1 billion pounds for vinyl chloride in 1963. The expected capacity will be adequate to meet the anticipated growth in consumption for both polyvinyl chloride and polyethylenes.

Projections of production from 1959 to 1963 based upon growth patterns in the 1949-1958 period, and anticipated growth, are used to estimate possible plasticizer consumption in 1963. The industrial interviews indicate that the production of thermoplastics by 1963, based upon knowledge available in 1958, would indicate continued growth in plasticizer production and use.

The graphic extension of production through 1963 for both polyethylenes and polyvinyl chloride is modified by the anticipated effect in this rapidly changing industry from:

(1) A decline in the rate of expansion of production capacity;

(2) Idle capacity which will likely increase gradually as competition between polymers increases; and

(3) The change in rate of increase of market expansion of polyethylenes and polyvinyl chloride, as primary volume markets are saturated and less promising markets in terms of volume of use remain to be exploited.

The above factors, plus the commercial development of copolymers, by 1963 are expected to create a more "mature" market situation for PVC and polyethylenes. That is, after 1963, PVC and polyethylenes production and marketing will be governed more by population growth and the general level of business than by new product development and market exploitation.

THE POTENTIAL FOR FAT-BASED PLASTICIZERS

Trends in Use

The characteristics desired in plasticizers in the 1959-1963 period are not likely to be radically different that those desired in the 1954-58 period. The market for fat-based plasticizers will continue to depend on the production of PVC and cellulosics, although the importance of cellulosics in relation to polystyrene, nitrile and chlorine containing rubbers, and extruded nylons will diminish. The economic and technical requirements for plasticizers will be those required of PVC in various applications. Fat-based plasticizers must, therefore, continue to meet the needs of fabricators in present applications as well as to be adaptable to new applications of PVC resins.

The trend in requirements since 1954 has been heavily toward greater use of dibasic acids for plasticizers (azelaic and sebacic) while oleic acid use has declined.[5] That is, to obtain improved plasticizers and plastic products the trend has been to produce more complex compounds to improve the available plastic characteristics.

Briefly, the trend is toward materials which are more reactive to other chemicals in forming new chemical compounds than the saturated, monobasic materials.

Factors Favoring Use

Three general factors which will favor continued uses of plasticizers from fats in the 1959-63 period are:

(1) Price fluctuations of fatty materials have been reduced by chemical modifications and processes which have made fatty materials more readily substitutable for each other. The same fatty acids can be derived from different fats and oils.

(2) Fat-based plasticizers do not necessarily compete, pound for pound, in use with other plasticizers, and in many uses are supplementary. Therefore, growth in the use of one type will result in growth in application of the other; and

(3) Current research developments have demonstrated that fatty materials can be used as chemical building blocks to modify and improve functional characteristics of plasticizer materials not anticipated in the past.

Except for possible research developments which might alter the technical and economic relationships between competitive materials, continued, but more limited, growth in consumption of plasticizers for derivatives of farm produced fats and oils is in prospect.

[5] The lack of substantial trend in adipic acid, is an exception.

Factors Limiting Use

The factors which will continue to limit the expansion in use of farm produced fats and oils in plasticizers are:

(1) Increased competition from materials not requiring plasticizers;

(2) Price of individual fats and oils will continue to be governed by values in other markets rather than being competitively priced with other plasticizer materials; and

(3) Limited chemical reactivity limits processes used in developing plasticizers of greater utility from fats. Procedures now require relatively expensive chemical modification.

The balance between the expansion of consumption of fat plasticizers and limitations thereto can be altered by continued technological advance.

The use of fat in plasticizers may be limited more by a chemical process now being adapted to commercial production whereby fatty alcohols can be produced from petroleum. Potentially these fatty alcohols can be produced more cheaply than derivatives from agriculture.

The ability to produce fatty alcohols commercially from petroleum points up the threat to continued use of an agricultural derivative by industry. Although fats and oils have been used for non-edible purposes for centuries, the progress in commercial organic chemistry since World War II threatens to change this situation rapidly. However, in the short-run, 1960-1963, total production of plasticizer using PVC plastic will have the greatest influence on plasticizer production.

Estimated Fat-Based Plasticizer Production--1963

The strength of the relationship between PVC production and plasticizer production may be used to project fat-based plasticizer production for 1963.

The ratio of plasticizer production to PVC production for 1963, as projected from production trends and this study, is .63 to 1.

A continuation of the relatively stable relationships among groups of plasticizers in the short-run is expected to result in a ratio of fat-based plasticizer production of about 17 percent of the total for plasticizers for 1963, or 102 to 107 million pounds.

The relationship between epoxy fats and oils and PVC production may also be used to estimate future production. Recommended formulas for plasticized PVC plastics indicate that production of epoxy fats and oils may stabilize around a .05 to 1 ratio to PVC production. Production in 1963 of epoxy fats and oils is therefore projected at 48 to 50 million pounds, or 47 percent of total fat-based plasticizer.

MARKET DEVELOPMENT THROUGH RESEARCH

Fat Plasticizers and Plastics Characteristics

A plasticized plastic is generally a compromise of desired characteristics. To improve one characteristic often impairs another. The most serious drawback to plasticizer-polymer systems has been the migration of plasticizer from the plastic product due to a variety of causes. The compatibility of plasticizer and plastic becomes very important in choosing the plasticizer to use in a specific application.

Derivatives of fat used as plasticizers have been restricted in use by limited compatibility with plastics. Research developments that increase the proportion of plasticizer which will remain in a polymer under heat, light, and stress, will generally increase utilization of a particular plasticizer.

Another attribute of fatty materials as sources for plasticizers is that obtaining a desired product by chemical modification of the fat molecule becomes a relatively expensive operation. Processing fats becomes expensive because of the cost of obtaining the degree of purity required for use as a plasticizer; and the nature of the reactivity of the fat molecule results in low yields of desired product per unit of raw material.

A third major difficulty arises concerning the development of new plasticizer materials based on derivatives of farm produced fats. The comparative markets for derivatives of fats and oils in soap, or other detergents, paints, surface active agents, and many other industrial uses with plasticizers, result in only limited economic incentive and resources being applied to the problem. The 55 million pounds of fatty acids used in plasticizers is small in relation to the billions of pounds of fats and oils produced each year, and the hundreds of millions of pounds of fatty acids produced from fats and oils.

Possible Developments

The plastics industry has started to expand the use of plastics for construction of homes and industrial buildings. Plastic floor coverings, plastics for metal coatings, and even shoes of plastic materials, offer sizeable markets yet to be exploited. These uses have not been important markets for fat materials.

The present limitation to plasticizer materials for construction uses is directly related to the unwanted physical characteristics of plasticizers. The difficulty lies in the possible economics of improved plasticized materials competing with internally plasticized materials which do not require plasticizers.

Fat-based compounds adding the following characteristics to plasticized plastics could expand use of fat-based plasticizers:

(1) A plasticized plastic which could be boiled in water without damage. Plasticizers made from fats and oils derivatives provide good low temperature characteristics, which is an important factor in the use of epoxies, as well as sebacates and azelates;

(2) A plasticizer that would make a plastic flexible yet produce a hard surface is a characteristic not now attainable with plasticized materials;

(3) A prime problem in the development of more suitable edible type plasticizers is the cost of testing the product for toxicity. The time consumed in addition to the difficult procedures, in relation to present markets, definitely discourages adequate development. The costs of development require a selling price which would seriously restrict the economic use of the new edible plasticizers;

(4) A plasticized plastic which would have improved outdoor aging characteristics would broaden the competition between vinyls and other plastics for outdoor uses.

Volume use of plasticizers from fatty materials is definitely limited by price unless unique or improved properties can be obtained. A drastic price reduction would be needed to increase use through price alone. A reduction of 10 cents per pound in price for plasticizers now selling for 30 to 40 cents per pound might increase consumption to a significant degree, but the manufacturer would undoubtedly find it unprofitable.

The basic development possibilities for expanded markets for fat through chemical research may also be applied to other sources of carbon materials.